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(54) **Optical amplifier and optical communication system provided with the optical amplifier.**

(57) An optical amplifier amplifying a received optical signal, comprising:

- a) a first optical coupler splitting the received optical signal into a first input optical signal and a second input optical signal;
- b) a detector for receiving the second input optical signal and for detecting the received optical signal level;
- c) a pumping light source emitting a pumping light beam;
- d) an optical fiber, doped with a rare earth element, having an input and an output; and,
- e) a second optical coupler for introducing the first input optical signal and the pumping light beam to the input of said optical fiber to amplify the first input optical signal.

An optical transmission system for transmitting an optical signal, comprising:

- a) a first and a second optical fiber;
- b) a first terminal station for transmitting an optical signal to an input end of the first optical fiber;
- c) a second terminal station for receiving the optical signal from an output end of the second optical fiber;

d) an optical amplifier, optically connected to the output end of the first optical fiber and the input end of the second optical fiber, for amplifying the optical signal from the output end of the first optical fiber, including,

an rare earth element doped optical fiber having an input and an output;

means for receiving the optical signal from the output end of said first optical fiber and for splitting the input optical signal into a first input optical signal and a second input optical signal;

a detector for receiving and monitoring the second input optical signal;

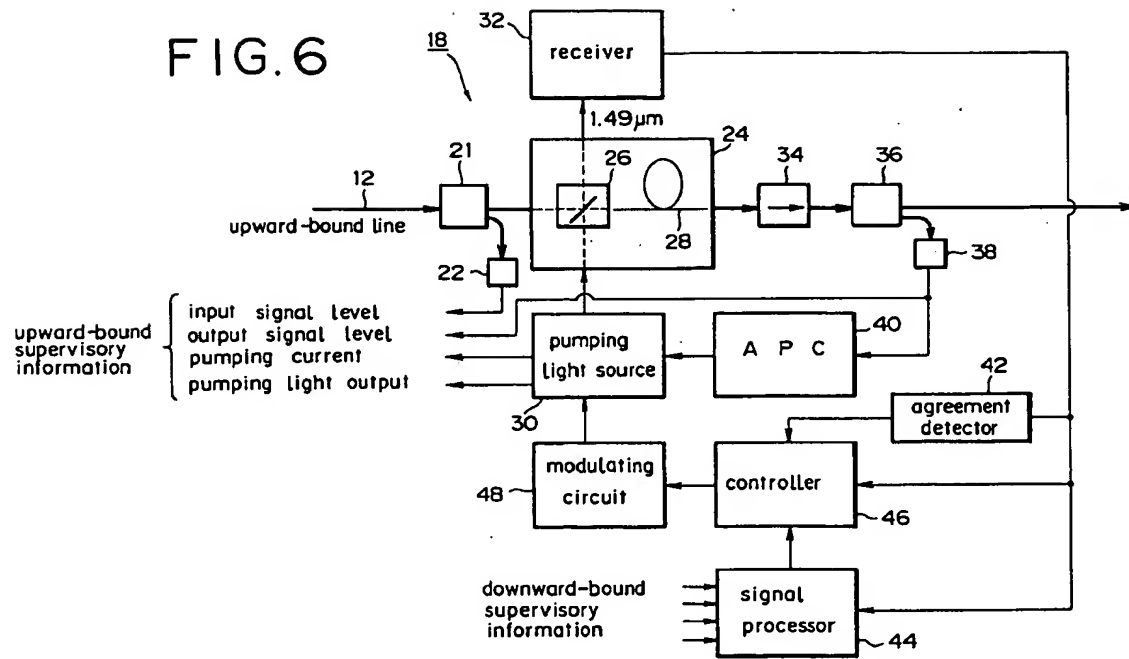
means for inputting the first input optical signal to the input of said rare earth element doped fiber;

a pumping light source, optically coupled to either the input or the output of the rare earth element doped fiber, emitting a pumping light beam introduced to either the input or the output of the rare earth element doped fiber;

means for optically connecting the output of the rare earth element doped optical fiber to the input end of the second optical fiber.

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FIG. 6



### Background of the Invention

The present invention relates to an optical communication system provided with an optical fiber amplifier and, more particularly, to an optical communication system provided with an optical fiber amplifier constituted of a rare-earth-doped fiber doped with a rare earth element.

Optical amplifiers capable of amplifying an optical signal directly, not using an electric circuit, is being intensively studied in many research institutions as a key device in the optical communication system in the future because of their bit-rate-free characteristic, readiness to provide large capacity, and capability of amplifying multiple channels en bloc. As optical communication systems including such optical amplifiers, there are proposed such that employs the optical amplifier as an optical power booster for compensating for branching or insertion loss and increasing the transmission power, that uses the optical amplifier as an optical preamplifier for improvement of reception sensitivity, that uses the optical amplifier as an optical repeater whereby miniaturisation of the repeater is achieved and reliability on the repeater is enhanced, and so on. Researches are being conducted for optimized arrangement of such systems.

Optical amplifiers being the objects of the researches conducted so far are broadly classified into: (a) the one using an optical fiber doped with a rare earth element such as Er, Nd, and Yb (hereinafter referred to as "rare-earth-doped fiber", this term covering a wide range of waveguide structures including a waveguide doped with a rare earth element); (b) the one being of a semiconductor laser type; and (c) the one making use of the non-linearity within an optical fiber. Of these, the optical amplifier (a) above, i.e., that uses a rare-earth-doped fiber, has such advantageous characteristics that it has no dependency on polarization, produces low noise, and incurs a small loss at its coupling with the transmission line.

When an optical amplifier is used as an optical repeater, a supervisory control function for it is indispensable. As a supervisory system applicable to the optical amplifier (b) above, i.e., the one being of a semiconductor laser type, there is known a system disclosed, for example, in *Ellis, A.D. et al.: Supervisory system for cascaded semiconductor laser amplifier repeaters, Electron. Lett., Vol. 25, No. 5, PP. 309-311 (2nd March 1989)*. Since this system is such that the injection current to the semiconductor laser type optical amplifier is detected therein, the same system as it is cannot be applied to the optical communication system provided with an optical fiber amplifier. In other words, there is found no prior art supervisory control system suitable for optical fiber amplifiers.

### Summary of the Invention

An optical communication system provided with an optical fiber amplifier uses a pumping light beam to effect the optical amplification. Hence, if transmission of information using the pumping light beam can be performed in the system in addition to transmission of information with a signal light beam, then, it becomes possible to have supervisory control performed in the optical communication system provided with the optical fiber amplifier as an optical repeater. Since the optical amplification of a signal light beam is effected not only when a pumping light beam introduced into a rare-earth-doped fiber is in the same direction as the signal light beam but also when it is in the opposite direction to the signal light beam, if transmission of information is possible with the use of the pumping light beam, it becomes possible to achieve a two-way transmission by making use of such characteristics.

Accordingly, an object of the present invention is to provide an optical communication system having an optical fiber amplifier capable of transmission of information with a pumping light beam, in addition to transmission of information with a signal light beam.

In accordance with an aspect of the present invention, there is provided an optical communication system having an optical repeater including an optical fiber amplifier adapted to amplify a signal light beam by having the signal light beam and a pumping light beam propagated through its rare-earth-doped fiber doped with a rare earth element, the system comprising a pumping light source for emitting the pumping light beam, and means for modulating the pumping light beam with a high-frequency modulating signal having a period shorter than the life span of fluorescence resulting from an excited state, whereby transmission of information with the pumping light beam acting as the carrier, in addition to transmission of information with the signal light beam, is made achievable.

Since it is adapted in the present invention such that the pumping light beam is modulated by a high-frequency modulating signal with a period shorter than the life span of the fluorescence resulting from an excited state, it is made possible to achieve transmission of information with the pumping light beam, in addition to transmission of information with the signal light beam, without adversely affecting the amplification of the signal light beam by the pumping light beam. Consequently, in the case where the signal light beam and the pumping light beam are arranged to be propagated in the same direction through the rare-earth-doped fiber, it can be simply achieved to transmit a supervisory signal for an optical repeater by using the

pumping light beam as the carrier. In the case where the signal light beam and the pumping light beam are arranged to be propagated in the directions opposite to each other through the rare-earth-doped fiber, a two-way transmission can be achieved by transmission of information with the signal light beam and transmission of information with the pumping light beam. The transmission of information with the pumping light beam includes a transmission of supervisory signal for an optical repeater.

The above and other objects, features and advantages of the present invention and the manner of realizing them will become more apparent, and the invention itself will best be understood, from a study of the following description and appended claims, with reference had to the attached drawings showing some preferred embodiments of the invention.

#### Brief Description of the Drawings

FIG. 1 is a schematic diagram showing the principle of optical amplification effected by a rare-earth-doped fiber;

FIG. 2 is an explanatory drawing of fluorescence;

FIG. 3 is an explanatory drawing of the life span of fluorescence;

FIG. 4A is an explanatory drawing of the principle of the present invention in the case where the signal light beam and the pumping light beam are in the same direction;

FIG. 4B is an explanatory drawing of the principle of the present invention in the case where the signal light beam and the pumping light beam are in the opposite directions;

FIG. 5 is an explanatory drawing of an optical repeater unit according to an embodiment of the present invention;

FIG. 6 is a block diagram of an upward-bound repeater according to an embodiment of the present invention; and

FIG. 7 is a block diagram of a two-way transmission system according to an embodiment of the present invention.

#### Description of the Preferred Embodiments

FIG. 1 shows the principle of optical amplification by means of a rare-earth-doped fiber. Reference numeral 2 denotes a rare-earth-doped fiber formed of a core 2a and a clad 2b, of which the core 2a is doped with a rare earth element such as erbium (Er). When a pumping light beam is led into such a rare-earth-doped fiber 2, the rare earth atoms are excited to an high energy level. When a signal light beam is allowed to impinge on the rare

earth atoms excited to the high energy level within the optical fiber 2, stimulated emission of light takes place causing transition of the rare earth atoms to the ground state, whereby the intensity of the signal light beam is progressively increased along the optical fiber, and thus, amplification of the signal light beam is effected. In the case where the doped rare earth element is erbium (Er), a laser beam whose wavelength is 1.49  $\mu$  m band, for example, can be used as the pumping light beam when the signal light beam with a wavelength of 1.55  $\mu$  m band is to be amplified. In the case where the doped rare earth element is neodymium (Nd), a laser beam whose wavelength is 0.8  $\mu$  m band, for example, can be used as the pumping light beam when the signal light beam with a wavelength of 1.3  $\mu$  m band is to be amplified. In the following, description of the present invention will be made assuming that the doped rare earth element is erbium.

When a pumping light beam with a wavelength  $\lambda_p$  is led into a rare-earth-doped fiber through which a signal light beam with a wavelength  $\lambda_s$  is being propagated, the wavelength  $\lambda_p$  being in a predetermined wavelength relationship with the wavelength  $\lambda_s$ , there is produced fluorescence whose spectrum is as shown by character F in FIG. 2 within the rare-earth-doped fiber in the vicinity of the spectrum of the signal light beam. The variation in the intensity of the fluorescence with time is not completely coincident with the variation in the intensity of the pumping light beam with time, that is, as shown in FIG. 3, supposing that the introduction of the pumping light beam is stopped at time  $t_0$ , the intensity of the fluorescence does not become zero instantly, but it gradually decreases taking a certain time constant. When the life span of fluorescence is defined as the time  $\tau$  which is taken for the intensity I of the fluorescence to decrease from its value  $I_0$  obtainable before the introduction of the pumping light beam is stopped to  $1/e$  of  $I_0$  - (e: the base of natural logarithm), it is known that, even if the introduction of the pumping light beam is stopped, the amplification action for the signal light beam is maintained without causing unstable variations in the gain for a period of time within the range from the point of time to  $t_0$ , approximately, when the life span of fluorescence  $\tau$  elapses (*Lam-ing, R.I. et al.: Multichannel cross talk and pump noise characterization of  $Er^{3+}$ -doped fibre amplifier pumped at 980 nm, Electron. Lett., Vol. 25, No. 7, pp. 455-456 (30th March 1989)*).

Accordingly, in the case where a pumping light beam is modulated by a high-frequency modulating signal whose period is shorter than the life span of fluorescence resulting from the excited state or thereabout, the modulation does not have an adverse effect on the amplification of the signal light

beam.

Referring to FIG. 4A and FIG. 4B, FIG. 4A is for describing the principle of the present invention in the case where the signal light beam and the pumping light beam are propagated in the same direction through a rare-earth-doped fiber, whereas FIG. 4B is for describing the same in the case where the signal light beam and the pumping light beam are propagated in the directions opposite to each other through a rare-earth-doped fiber.

The system of the present invention is such that, in an optical communication system provided with an optical fiber amplifier for amplifying a signal light beam 4 by having the signal light beam 4 and a pumping light beam 6 propagated through a rare-earth-doped fiber 2 doped with a rare earth element, the pumping light beam 6 is modulated by a high-frequency modulating signal 8 with a period shorter than the life span of fluorescence resulting from an excited state or thereabout, whereby transmission of information with the pumping light beam 6 acting as the carrier, in addition to transmission of information with the signal light beam 4, is made achievable.

Here, the rare-earth-doped fiber doped with a rare earth element has, as described above, a wide meaning that covers general waveguide structures such as waveguides doped with a rare earth element. Therefore, an optical fiber amplifier achieving amplification of a signal light beam by propagating the signal light beam together with a pumping light beam through a rare-earth-doped fiber doped with a rare earth element covers not only optical amplifiers which use optical fibers as propagating media of light but also optical amplifiers using optical waveguide structures such as optical waveguides as propagating media of light.

When the signal light beam and the pumping light beam are propagated in the same direction through the rare-earth-doped fiber as shown in FIG. 4A, transmission of a supervisory signal for the optical repeater with the pumping light beam acting as the carrier can be achieved.

On the other hand, when the signal light beam and the pumping light beam are propagated in the directions opposite to each other through the rare-earth-doped fiber as shown in FIG. 4B, a two-way transmission by transmission of information with the signal light beam and transmission of information with the pumping light beam acting as the carrier can be achieved.

FIG. 5 is an explanatory drawing of an optical repeater unit with the present invention applied thereto. The drawing shows a system of a two-way optical transmission lines formed of an upward-bound optical transmission line 12 and a downward-bound optical transmission line 14 with a single or a plurality (three in the illustrated case) of

optical repeater units 16 provided in the way of the two-way optical transmission lines. The optical repeater unit 16 includes an upward-bound repeater 18 connected with the upward-bound optical transmission line 12 and a downward-bound repeater 20 connected with the downward-bound optical transmission line 14. These upward-bound repeater 18 and downward-bound repeater 20 perform communication of supervisory information therebetween for achieving a supervisory control function for the optical repeater unit in addition to general repeater functions. While the communication of the supervisory information between the upward-bound and downward bound repeaters 18 and 20 is achieved by means of electric signals, the transmission of supervisory information through the optical transmission lines 12 and 14 is achieved by means of pumping light beams propagated through rare-earth-doped fibers included in the optical repeater unit 16.

FIG. 6 is a block diagram of the upward-bound repeater 18. The downward-bound repeater 20 has the same block structure as the upward-bound repeater 18. Referring to FIG. 6, the wavelength of the signal light beam propagated through the upward-bound optical transmission line 12 is  $1.536 \mu\text{m}$ , or  $1.552 \mu\text{m}$ , for example, and the wavelength of the pumping light beam is  $1.49 \mu\text{m}$ , for example. The portion of the pumping light beam which has not contributed to the optical amplification arrives at an upward-bound repeater 18. The signal light beam and the pumping light beam are split by an optical coupler 21 into portions in the ratio of 1:100, for example. The smaller split portion of the beams is input to an input signal level detector 22 for level detection of the signal light beam. The larger split portion of the beams is input to an optical fiber amplifier 24.

The optical fiber amplifier 24 comprises a dichroic coupler 26 and a rare-earth-doped fiber 28 with its core doped with erbium. The dichroic coupler 26 splits the beams from the optical coupler 21 into the signal light beam and the pumping light beam, and leads the signal light beam into the rare-earth-doped fiber 28 and the pumping light beam to a receiver 32. The dichroic coupler 26 further reflects a pumping light beam from a pumping light source 30 and leads it into the rare-earth-doped fiber 28.

The signal light beam amplified by the optical fiber amplifier 24 and the portion of the pumping light beam not consumed in the amplification of the signal light beam together are input to an optical coupler 36 through an optical isolator 34. The optical isolator 34 is provided for preventing oscillation from occurring due to gain of the rare-earth-doped fiber 28 as the result of formation of a resonator structure in the optical path including the

rare-earth-doped fiber 28. The optical coupler 36 splits the input signal light beam and pumping light beam into portions in the ratio of 1:100, of which the larger split portion of the beams is reintroduced into the upward-bound optical transmission line 12 and the smaller split portion of the beams is input to an output signal level detector 38. The output signal level detector 38 suppresses the pumping light beam by means of an optical filter incorporated therein and detects the level of the amplified signal light beam.

The pumping light source 30 is constituted of a semiconductor laser in the present embodiment and the intensity of the pumping light beam output therefrom or the average value thereof is controlled so that the level of the above described output signal may become constant by means of an APC circuit 40 depending on the signal output from the output signal level detector 38. By virtue of the described control, it becomes possible to have the signal light beam held at a constant level output from the upward-bound repeater 18 at all times regardless of the level of the signal light beam input to the upward-bound repeater 18.

The input signal level from the input signal level detector 22, the output signal level from the output signal level detector 38, the pumping current (the bias current for the semiconductor laser) in the pumping light source 30, and the pumping light output from the same are delivered to the downward-bound repeater 20 as upward-bound supervisory information, which is delivered to the downward-bound optical transmission line 14 by modulating the pumping light beam there (also refer to FIG. 5).

On the other hand, downward-bound supervisory information is accepted by the upward-bound repeater 18 through a signal processor 44 and the pumping light beam from the pumping light source 30 is modulated by the downward-bound supervisory information, whereby the downward-bound supervisory information is transmitted through the upward-bound optical transmission line 12. The detailed operation of the above will be described in the following. A delivery command of the downward-bound supervisory information to the upward-bound repeater 18 is received by the receiver 32 of the upward-bound repeater and, thereupon, the receiver 32 decodes the command and inform a controller 46 of the decoded command. This decoding can be achieved by subjecting the address information received by the receiver 32 to detection performed in an agreement detector 42, as to whether it is in agreement with the address information stored therein in advance. The controller 46, upon receipt of the delivery command of the supervisory information, controls a modulating circuit 48 depending on the downward-bound supervi-

sory information from the signal processor 44 and, thereby, the pumping light beam from the pumping light source 30 is intensity-modulated, for example. By arranging the modulation speed at this time to be sufficiently higher than the reciprocal of the life span of the fluorescence in the rare-earth-doped fiber 28, even if the pumping light beam from the pumping light source 30 is modulated, the modulation component hardly appears in the signal light beam amplified in and delivered from the upward-bound repeater 18. Thus, it becomes possible to achieve transmission of supervisory information carried by the pumping light beam acting as the carrier in addition to transmission of information with the signal light beam that is directly amplified. In the case where both the sets of address information are not in agreement in the agreement detector 42 and, therefore, there is no necessity for delivering the downward-bound supervisory information to the upward-bound optical transmission line 12, it is arranged such that the supervisory information carried by the pumping light beam accepted from the preceding stage by the receiver 32 is reproduced and amplified by the controller 46 and the thus obtained information is used for modulating the pumping light source 30.

FIG. 7 is a block diagram showing an arrangement of a two-way transmission system with the present invention applied thereto. This system has a first terminal station 50 and second terminal station 52 connected through a single optical fiber 54 to achieve the two-way transmission. The first terminal station 50 comprises a transmission portion 56 for transmitting a signal light beam of 1.55  $\mu$  m band, a reception portion for receiving a modulated pumping light beam of 1.49  $\mu$  m band, and a dichroic coupler 58. The second terminal station 52 comprises a preamplifier 62, a reception portion 64 for receiving the signal light beam of 1.55  $\mu$  m band, and a transmission portion 66 for modulating and transmitting the pumping light beam of 1.49  $\mu$  m band. The transmission portion 66 includes a pumping light source 68 and a modulating circuit 70 for intensity-modulating the semiconductor laser of the pumping light source 68. The preamplifier 62 includes a rare-earth-doped fiber 72 connected with the optical fiber 54 and a dichroic coupler 74 for both leading the modulated pumping light beam into the rare-earth-doped fiber 72 and delivering the signal light beam amplified by the rare-earth-doped fiber 72 to the reception portion 64.

The signal light beam from the transmission portion 56 of the first terminal station 50 is delivered to the optical fiber 54 through the dichroic coupler 58 and, then, amplified by the preamplifier 62 of the second terminal station 52 and received by the reception portion 64. At this time, since the

signal light beam is amplified by action of the preamplifier 62 (optical fiber amplifier), the reception sensitivity is enhanced. On the other hand, the modulated pumping light beam delivered from the transmission portion 66 of the second terminal station 52 contributes to the amplification of the signal light beam from the first terminal station 50 producing no effect of its modulated state on the signal light beam and, then, it is transmitted to the first terminal station 50 through the optical fiber 54 and accepted by the reception portion 60 so that the transmitted information is reproduced therein.

Since the signal light beam and the pumping light beam are adapted to be propagated in the directions opposite to each other through the rare-earth-doped fiber 72, the two-way transmission is achieved by the transmission of information with the signal light beam and by the transmission of information with the pumping light beam acting as the carrier.

The modulation of the pumping light source 68 in the transmission portion 66 of the second terminal station 52 is performed, the same as in the embodiment described with reference to FIG. 5 and FIG. 6, by a high-frequency modulating signal having a period shorter than the life span of fluorescence resulting from the excited state in the rare-earth-doped fiber or thereabout.

In the case where the rare-earth-doped fiber is that doped with erbium as the rare earth element, the life span of fluorescence resulting from the excited state is approximately 14 ms, for example, and, hence, a practically sufficient transmission capacity can be obtained.

#### Claims

1. An optical amplifier amplifying a received optical signal, comprising:
  - a) a first optical coupler splitting the received optical signal into a first input optical signal and a second input optical signal;
  - b) a detector for receiving the second input optical signal and for detecting the received optical signal level;
  - c) a pumping light source emitting a pumping light beam;
  - d) an optical fiber, doped with a rare earth element, having an input and an output; and,
  - e) a second optical coupler for introducing the first input optical signal and the pumping light beam to the input of said optical fiber to amplify the first input optical signal.
2. An optical amplifier, according to claim 1, wherein said detector detects the received optical signal level for forming supervisory signal.
3. An optical amplifier, according to claim 1, further comprising:
  - a) an optical isolator, optically coupled to the output of said optical fiber.
4. An optical amplifier, according to claim 1, further comprising:
  - a) means, optically coupled to the output of said optical fiber, for outputting the amplified first input optical signal.
5. An optical amplifier amplifying an input optical signal, comprising:
  - a) first means for splitting the input optical signal into a first input optical signal and a second input optical signal;
  - b) a detector for receiving and monitoring the second input optical signal;
  - c) an optical fiber, doped with a rare earth element, having an input and an output;
  - d) means for inputting the first input optical signal to the input of said optical fiber;
  - e) a pumping light source emitting a pumping light beam;
  - f) means for inputting the pumping light beam either to the input or the output of said optical fiber.
6. An optical amplifier, according to claim 5, wherein said detector monitors the second input optical signal for forming supervisory signal.
7. An optical amplifier, according to claim 5, further comprising:
  - a) an optical isolator, optically coupled to the output of said optical fiber.
8. An optical amplifier, according to claim 5, further comprising:
  - a) means, optically coupled to the output of said optical fiber, for outputting the amplified first input optical signal.
9. An optical transmission system for transmitting an optical signal, comprising:
  - a) a first and a second optical fiber;
  - b) a first terminal station for transmitting an optical signal to an input end of the first optical fiber;
  - c) a second terminal station for receiving the optical signal from an output end of the second optical fiber;
  - d) an optical amplifier, optically connected to the output end of the first optical fiber and the input end of the second optical fiber, for amplifying the optical signal from the output end of the first optical fiber, in-

cluding,

an rare earth element doped optical fiber having an input and an output;

means for receiving the optical signal from the output end of said first optical fiber and for splitting the input optical signal into a first input optical signal and a second input optical signal;

a detector for receiving and monitoring the second input optical signal;

means for inputting the first input optical signal to the input of said rare earth element doped fiber;

a pumping light source, optically coupled to either the input or the output of the rare earth element doped fiber, emitting a pumping light beam introduced to either the input or the output of the rare earth element doped fiber;

means for optically connecting the output of the rare earth element doped optical fiber to the input end of the second optical fiber.

10. An optical amplifier, according to claim 9, wherein said detector monitors the second input optical signal for forming supervisory signal.

11. An optical amplifier, according to claim 9, wherein said connecting means includes;

a) an optical isolator for allowing an output optical signal from said rare earth element doped fiber to propagate only from the output of said rare earth element doped fiber to the input end of the second optical fiber.

12. An optical transmission system for transmitting an optical signal, comprising:

a) a first and a second optical fiber, each having an input end and output end, respectively,

b) a first terminal station for transmitting an optical signal to the input end of the first optical fiber;

c) a second terminal station for receiving the optical signal from the output end of the second optical fiber;

d) an optical amplifier, optically connected to the output end of the first optical fiber and the input end of the second optical fiber, for amplifying the optical signal from the output end of the first optical fiber, including,

an rare earth element doped optical fiber having an input and an output;

a pumping light source emitting a pumping light beam;

first means for splitting the optical signal from the output end of the first optical fiber into a first and second input optical signal;

a detector for receiving and monitoring the second input optical signal;

second means for introducing the first input optical signal and the pumping light beam to the output of said rare earth element doped optical fiber;

means for optically connecting the output of the rare earth element doped optical fiber to the input end of the second optical fiber.



FIG.1

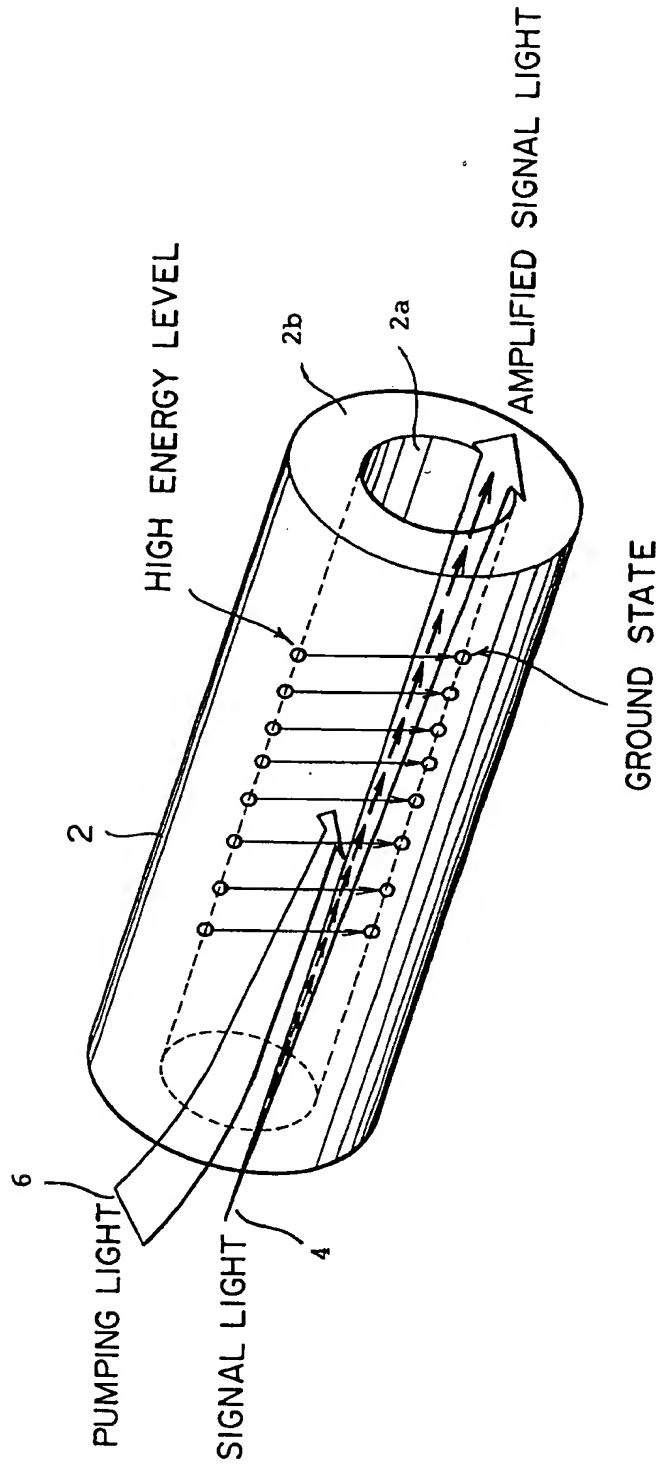


FIG.2

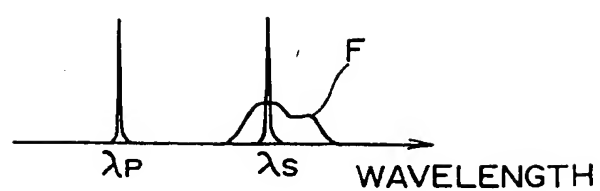


FIG.3

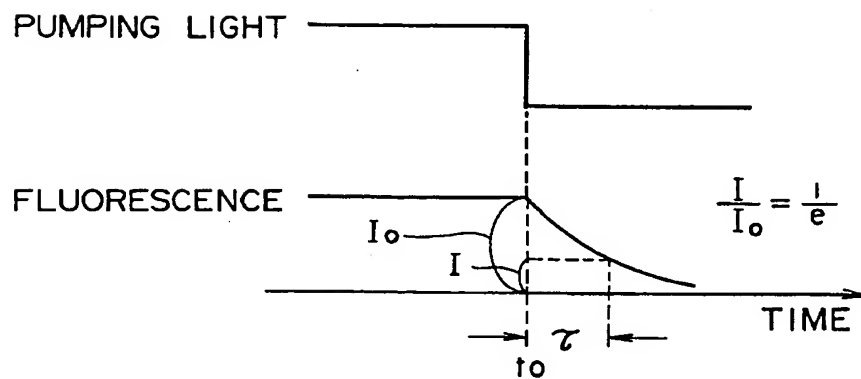


FIG. 4A

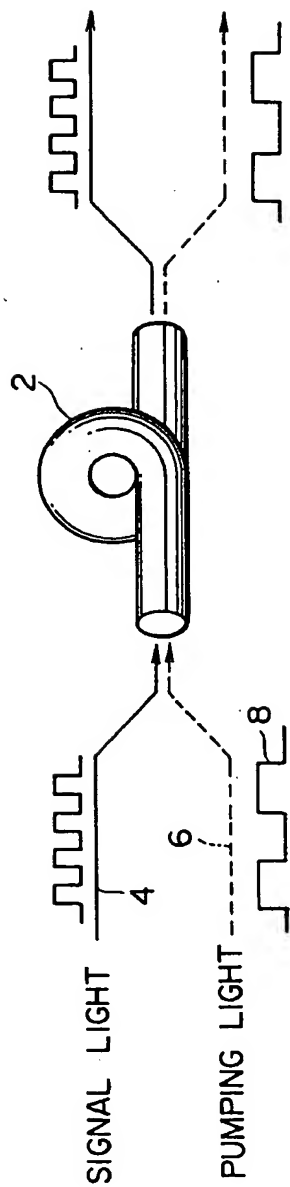


FIG. 4B

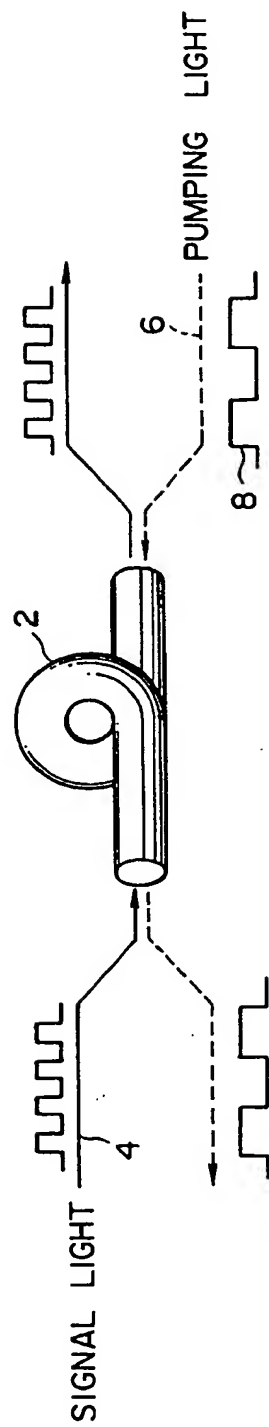


FIG. 5

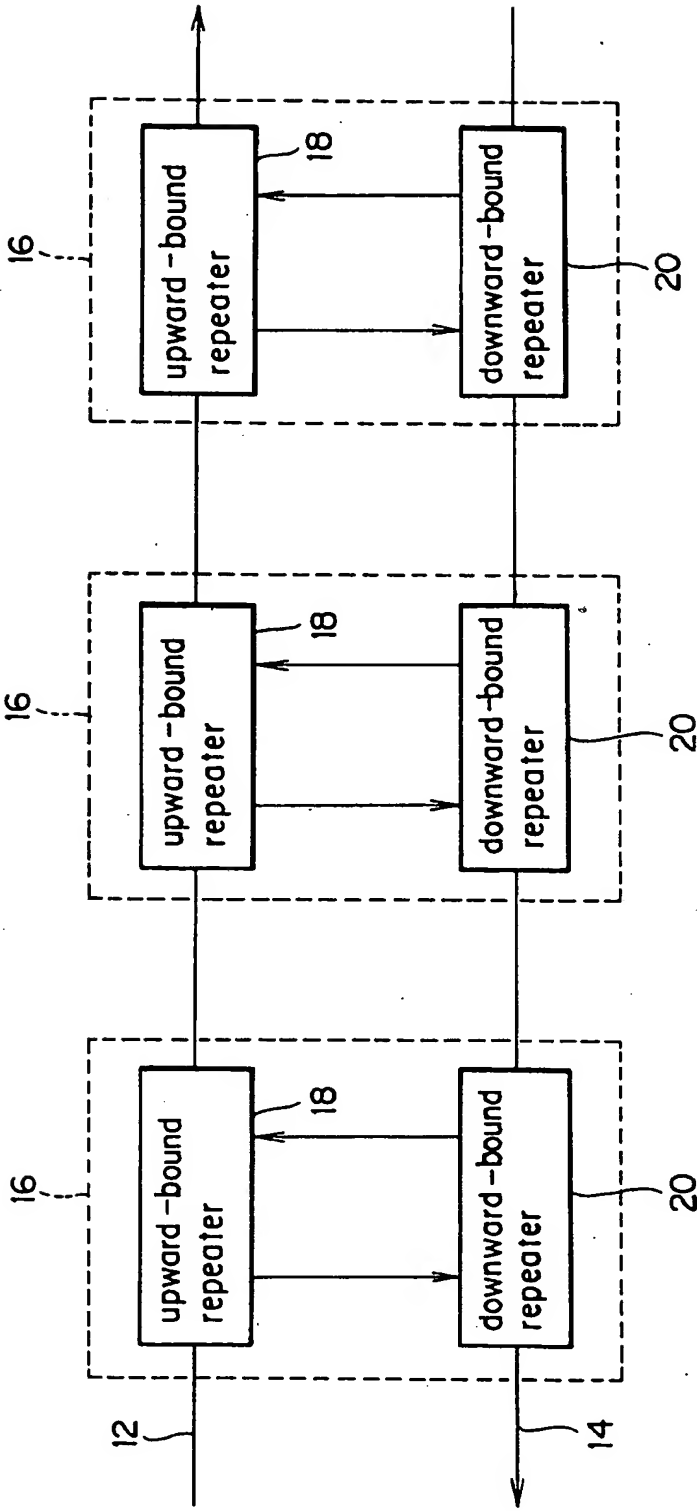


FIG. 6

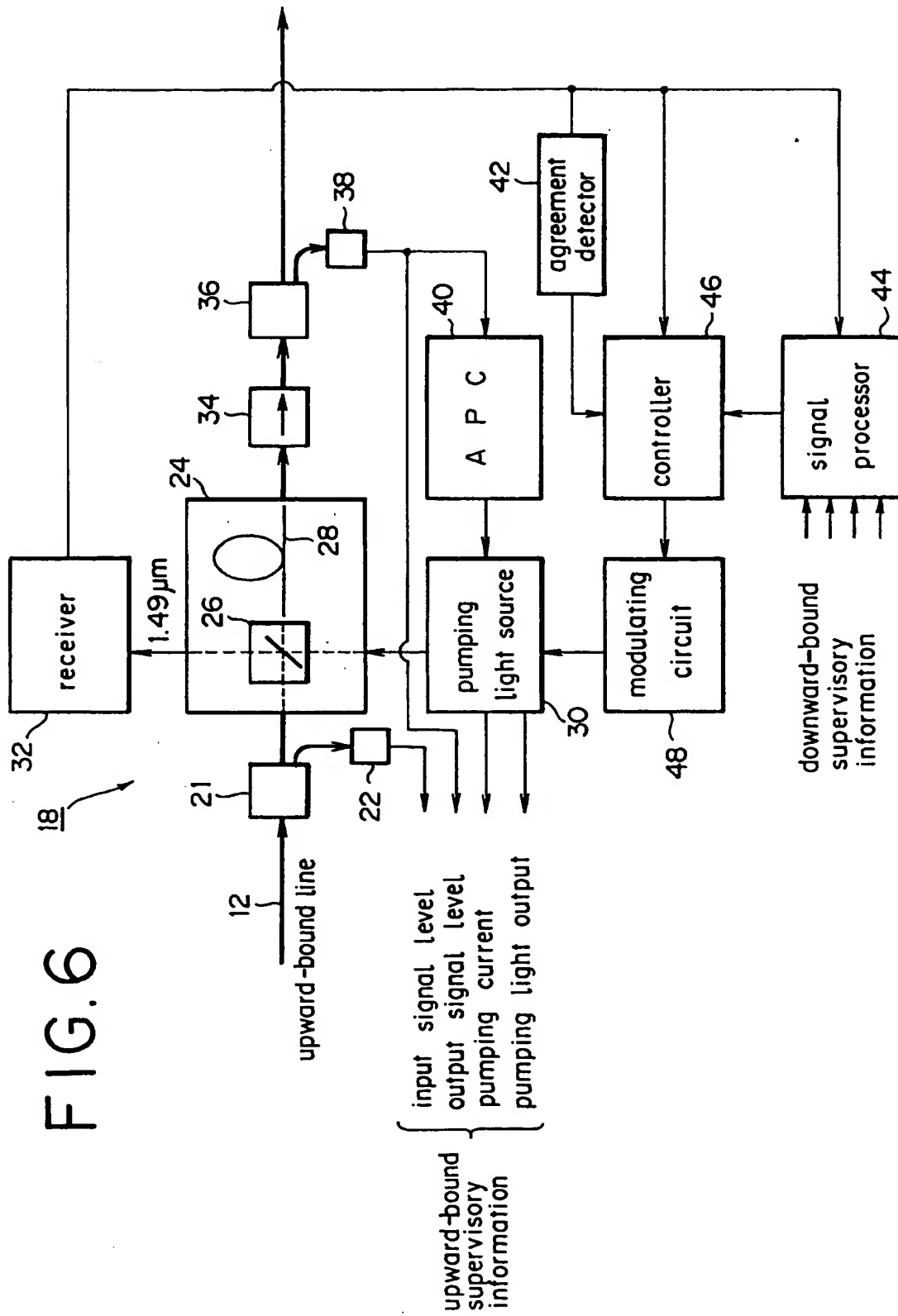


FIG. 7

